Summited via email

April 3, 2017

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Re: Request for Public Comment on Ocean Acidification Impacts in Oregon Marine Waters

Dear Jill Fullagar,

On behalf of the Center for Biological Diversity (The Center), I submit this letter regarding a request for public comments on data and information of ocean acidification impacts in Oregon's marine waters. In previous comments, the Center has provided significant information and supporting materials about the impacts of ocean acidification in Oregon's marine waters. As shown in the record for the proposed additions of the 2010 integrated report, on June 10, 2009, the Center submitted comments and scientific information requesting that EPA include coastal waters as impaired on Oregon's 303(d) list. On December 6, 2010, May 2, 2011, April 18, 2012, June 20, 2012, and in 2014, the Center submitted additional information and comments on ocean acidification for consideration in the Oregon water quality assessment. Since then, it has become more apparent that ocean acidification poses a serious threat to water quality with adverse effects to vulnerable marine and estuarine organisms. Here I discuss new studies and comment on previous studies on the impact of ocean acidification in Oregon's marine waters that EPA and the Oregon Department of Environmental Quality (ODEQ) should include and analyze for the 2012 and 2016 integrated report.

Specifically, the Center urges Oregon to list the following water bodies as threatened or impaired due to ocean acidification under its 303(d) Waster Quality Report:

a. NH-10 off Newport, OR (44.6°N, 124.3°W).
b. Oregon Inshore Surface Mooring at 7 m and 25 m deep (44.65828 ºN, -124.09525 ºW).
c. Oregon Shelf at 80 m deep (44.63708 ºN, -124.30595 ºW).
d. Oregon Shelf Surface Mooring at 7 m deep **(**44.63565 ºN, -124.30427 ºW).
e. Oregon Offshore at 580 m deep (44.3695 ºN, -124.95369 ºW)
f. Oregon Offshore Surface at 7 m deep (44.36485 ºN, 124.94343 ºW)

Additionally, Oregon must further obtain all readily available data on ocean acidification from sources listed in this letter (below) and analyze them for its water quality assessment.

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1. Oregon's marine and estuarine pH standards

Oregon's numerical pH criteria for marine waters (coastal and estuarine) are inadequate to address ocean acidification. The Oregon Department of Environmental Quality (ODEQ) should analyze whether marine waters are impaired by ocean acidification based on designated aquatic life uses and the associated narrative criteria. Oregon's pH criterion states that for marine waters, the pH must fall between 7.0 and 8.5 (OAR 340-041-0021). For estuarine and freshwaters, pH should fall within an even wider criteria from 6.5-9.0, depending upon location (OAR 340-041-0101 – a 340-041-0350). These criteria are very wide and most coastal and estuarine waters attain such standard. However, strong scientific evidence shows deleterious effects within these ranges for marine organisms (see below), even though pH fall within the acceptable range of the Oregon water quality standards. Therefore, numerical pH criteria for marine and estuarine waters are inadequate to address the ocean acidification problem. The EPA and ODEQ must analyze whether marine and estuarine waters are impaired by ocean acidification based on the narrative criteria related to aquatic life designated uses found at OAR 340-41-007(1) and (11). These narrative criteria state that:

(1) Notwithstanding the water quality standards contained in this Division, the highest and best practicable treatment and/or control of wastes, activities, and flows must in every case be provided so as to maintain dissolved oxygen and overall water quality at the highest possible levels and water temperatures, coliform bacteria concentrations, dissolved chemical substances, toxic materials, radioactivity, turbidities, color, odor, and other deleterious factors at the lowest possible levels.

(11) The creation of tastes or odors or toxic or other conditions that are deleterious to fish or other aquatic life or affect the potability of drinking water or the palatability of fish or shellfish may not be allowed . . .

Coastal and estuarine waters throughout the Oregon coast may already be experiencing the harmful effects of ocean acidification. Increasing concentrations of atmospheric carbon dioxide and the contribution of pollution, sedimentation, and inadequate watershed management can substantially amplify the fluctuating pH conditions in these waters making them more corrosive.

There is strong scientific evidence showing that growth, survival, and behavioral changes in marine species are linked to ocean acidification. These effects can extend throughout the food web, threatening coastal and estuarine ecosystems, coastal fisheries, and humans. Here, we present a summary of the most current scientific information on ocean acidification across Oregon marine, coastal and estuarine waters that should be considered to determine water impairment related to ocean acidification in the 2016 Integrated Report.

2. Oregon's marine waters affected by ocean acidification should be listed

a. Oregon's marine, coastal and estuarine waters are affected by ocean acidification

Impaired waters by ocean acidification should be included in the 2016 integrated report. Based on the designated aquatic life uses and associated narrative criteria, marine, coastal, and estuarine water affected by ocean acidification are not "*at the highest possible level*" and can be considered "*deleterious to fish and other aquatic life*". Ocean acidification may already impairing the capacity of organisms to produce shells and skeletons, altering food webs, and affecting the dynamic of entire coastal and estuarine ecosystems in Oregon (Hauri et al. 2009, Barton et al. 2012, Mackas and Galbraith 2012, Gruber et al. 2012, Lischka and Riebesell 2012, Hauri et al. 2013, Waldbusser and Salisbury 2014, Bednaršek et al. 2014, Ekstrom et al. 2015, Waldbusser et al. 2015a, Bednaršek and Ohman 2015, Barton et al. 2015, Chan et al. 2016, Bednaršek et al. 2016, Weisberg et al. 2016, Feely et al. 2016, Waldbusser et al. 2016, Feely et al. 2017, Bednaršek et al. 2017). Small increases in acidity of coastal and estuarine waters can substantially reduce the ability of marine organisms to produce shells and skeletons. Microscopic algae and calcifying zooplankton are especially at risk and changes in their abundance and survivorship can result in cascading effects that ripple through the entire food web, affecting other marine organisms from fishes to whales. Increasing CO_2 in seawater can also directly affect fishes by affecting critical behavior such as orientation, predator avoidance, and the ability to locate food and suitable habitat.

Oregon marine waters are vulnerable to ocean acidification because coastal upwelling amplifies the effect of anthropogenic CO_2 deposition. Coastal upwelling along the Oregon coast brings deep and cold water rich in CO_2 and low in oxygen to the continental shelf driving chemical conditions that are harmful to marine life (Feely et al. 2004, 2008, Hauri et al. 2009, Feely et al. 2009, Gruber et al. 2012, Hauri et al. 2013, Bednaršek et al. 2014). Because these processes happen in a multi-decadal time frame, the effects of ocean acidification due to anthropogenic CO_2 deposition across the North Pacific will become more severe overtime (Chan et al. 2016). Even if CO_2 emissions are halted today, Oregon marine waters (and west coast waters in general) have already committed to increased ocean acidification for the next three to four decades. In addition, coastal upwelling is projected to intensify in response to stronger winds due to global warming, which will only increase the prevalence of water of acidic and low oxygen conditions (Snyder et al. 2003, Sydeman et al. 2014).

In Oregon, ocean acidification in marine waters interacts with natural and anthropogenic processes that further reduce pH and carbonate saturation state (Feely et al. 2008, Salisbury et al. 2008, Hauri et al. 2009, Takeshita et al. 2015, Chan et al. 2016). Although, Oregon coastal waters are relatively more acidic because oceanic currents and coastal upwelling (Feely et al. 2004, 2008, Hauri et al. 2009, Feely et al. 2009, Hauri et al. 2013, McLaughlin et al. 2015, Turi et al. 2016), surface waters already show undersaturation with respect to aragonite due to anthropogenic ocean acidification independently of upwelling pulses (Feely et al. 2008, Carter et al. 2017). In fact, without acidification, undersaturated waters would have been as much as 50 m deeper than they are today (Feely et al. 2008).

Recent declines in aragonite saturation states due to anthropogenic ocean acidification have been compounded by changes in the circulation of the California Current (Feely et al. 2012), likely connected to climate change (Bakun 1990, Snyder et al. 2003, Sydeman et al. 2014) and that directly affect Oregon marine waters. Strong coastal upwelling along the Oregon coast occurs in the spring and summer supplying even more CO_2-rich waters from the deep ocean (Feely et al.

2008). Upwelling in this region has been intensified in the past decades (Rykaczewski and Checkley 2008) and it is predicted to become stronger with more favorable winds (Bakun 1990, Snyder et al. 2003, Sydeman et al. 2014). Models predict that by the mid-century, surface coastal waters in this region would remain undersaturated during the entire summer upwelling season and more than half of nearshore waters throughout the entire year (Gruber et al. 2012, Hauri et al. 2013).

Oregon coastal waters are already experiencing harmful conditions as a result of ocean acidification (Feely et al. 2010) even though they fall within the numeric standard criteria for pH (7.0-8.5) in the state. Oregon are among the first states to pass a threshold that is consider sub-lethal to marine organisms such as bivalves (Ekstrom et al. 2015) (Fig. 1a). Although models show that by mid-century coastal waters will be close to undersaturation (Cao and Caldeira 2008); estuarine waters today are undersaturated with respect to aragonite (Feely et al. 2010). These near and undersaturated waters in Oregon do not meet water quality standards - including designated uses, regardless of whether or not they attain current and inadequate pH numeric standards. Such prediction for the middle of the century (only 35 years from now) has tremendous implications for coastal waters in Oregon. Thus, the state must act now to improve water quality in coastal areas because 1), aragonite saturation state of some coastal and estuarine waters in Oregon are already suboptimal for oyster growth and reproduction (see below), and 2) control of stressors that magnify the effects of acidification at local scale must be implemented now to increase the probability of calcifying species to deal with higher acidification in the near future.

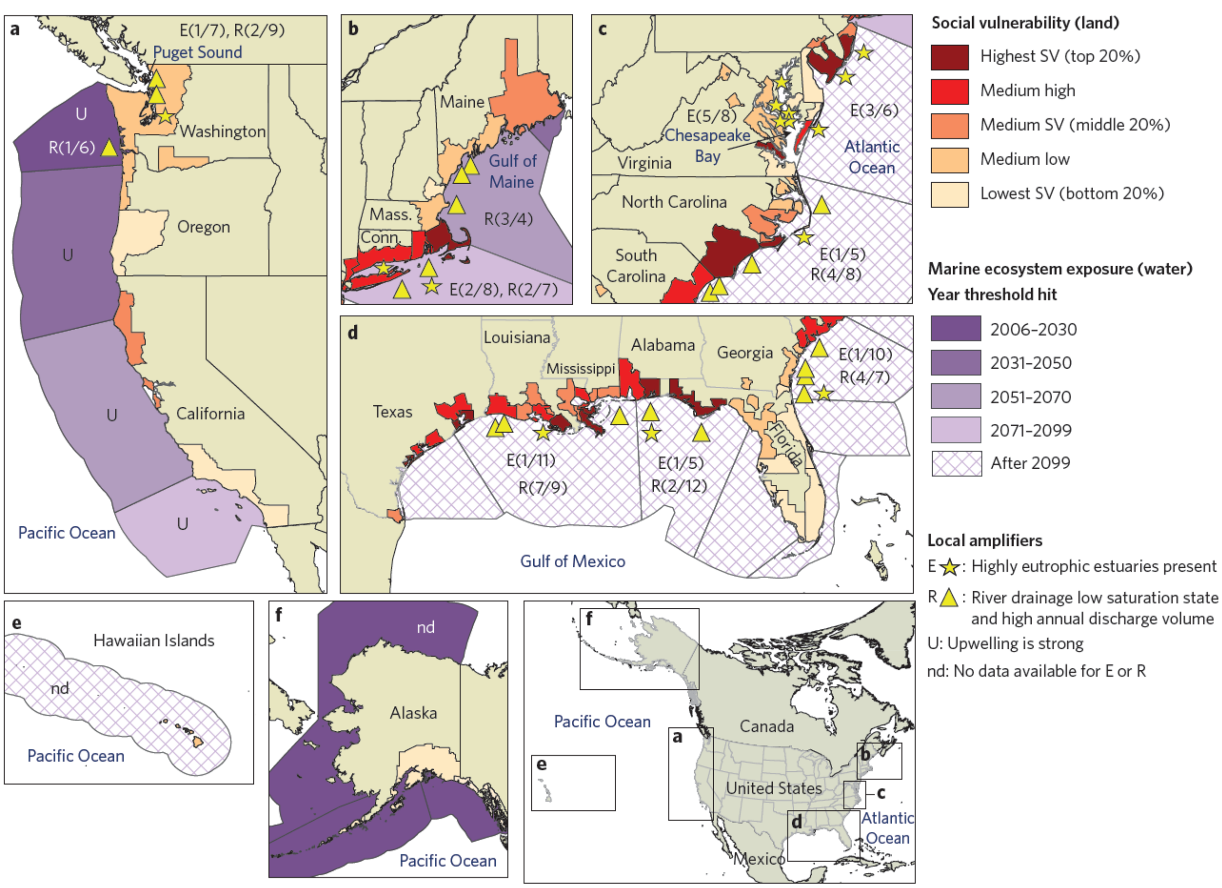


Figure 1. Vulnerability of coastal states to ocean acidification. **a-f**, Scores of relative social vulnerability are shown on land (by coastal county cluster) and the type and degree of severity of OA and local amplifiers to which coastal marine bioregions are exposed, mapped by ocean bioregion: US West Coast (**a**), Northeast (**b**), Chesapeake Bay (**c**), the Gulf of Mexico and the coast of Florida and Georgia (**d**), the Hawaii Islands (**e**), and Alaska (**f**). Social vulnerability (red tones) is represented with darker colors where it is relatively high. Exposure (purple tones) is indicated by the year at which sub-lethal thresholds for bivalve larvae are predicted to be reached, based on climate model projections using the RCP8.5 CO2 emission scenario. Exposure to this global OA pressure is higher in regions reaching this threshold sooner. Additionally, the presence and degree of exposure to local amplifiers of OA are indicated for each bioregion: E(x/y) marks bioregions in which highly eutrophic estuaries are documented, x is the number of estuaries scored as high, and y is the total number evaluated in each bioregion, locations of highly eutrophic estuaries are marked with a star; R(x/y) marks bioregions in which river water draining into the bioregion scored in the top quintile of an index designed to identify rivers with a very low saturation state and high annual discharge volume (calculated by authors from US Geological Survey data), x is the number of rivers scoring in the top quintile of those evaluated, and y is the total number evaluated in this study. Approximate locations of river outflows of those rivers scoring in the top quintile are marked with a yellow triangle, and U marks bioregions where upwelling is very strong in at least part of the bioregion. *Figure and legend after Ekstrom et al. (2015).*

Coastal and estuarine waters of Oregon are also influenced by local variability, and ocean acidification from coastal upwelling and atmospheric deposition can amplify these fluctuations. Daily and seasonal fluctuations in pH are due to changes in respiration, salinity, temperature and several local factors such as river discharge, eutrophication, hypoxia, and chemical contamination that amplify the deleterious effects of anthropogenic ocean acidification in coastal and estuarine waters (Fabry et al. 2008, Kelly et al. 2011, Cai et al. 2011, Waldbusser and Salisbury 2014). For example, ocean acidification combined with eutrophication can alter phytoplankton growth and succession affecting the entire base of food webs (Wu et al. 2014a, Flynn et al. 2015). Studies also show that under ocean acidification conditions heavy metal pollution can be more severe. In more acidic waters, sediments become more toxic as they easily bounds to heavy metals making them more available and thus more toxic for aquatic life (Roberts et al. 2013). For example, ocean acidification increases the toxicity effects of copper in some marine invertebrates (Campbell and Mangan 2014, Lewis et al. 2016).

b. Empirical and field studies show that marine calcifiers are highly vulnerable to ocean acidification in Oregon waters

Experiments have shown that ocean acidification has deleterious effects on many marine organisms (Feely et al. 2004, Cooley and Doney 2009, Hendriks et al. 2010, Kroeker et al. 2013, Waldbusser et al. 2015a, Yang et al. 2016) with long-term consequences for marine ecosystems (Hoegh-Guldberg 2007, Pandolfi et al. 2011, Couce et al. 2013, Nagelkerken and Connell 2015, Linares et al. 2015). Recent studies have confirmed that these adverse impact can be already detected in the field, despite several confounding factors such daily fluctuations in temperature, oxygen levels, salinity, and other variables (Yang et al. 2016, Albright et al. 2016, Bednaršek et al. 2016, Sunday et al. 2017). Calcifying organisms are clearly more vulnerable to the effects of ocean acidification than non-calcifying species (Kroeker et al. 2013) especially those that use aragonite as their calcium carbonate minerals (Ries 2010).

Most extant calcifying organisms use aragonite as the preferable crystal form of calcium carbonate to produce shells and skeletons and they are the most vulnerable to acidification (Ries 2010, Wittmann and Pörtner 2013). Organisms that use aragonite as the preferable form of calcium carbonate for calcification are the first to be affected as calcium carbonate plummets due to acidification. However, calcifying species have different thresholds for aragonite (i.e., the aragonite saturation state that prevents calcification and leads to dissolution is species specific), thus some marine calcifier species will be more vulnerable than others (Ries et al. 2009, Lebrato et al. 2016). Because marine calcifiers have different capacity to use the same concentration of calcium carbonate to secret shells and skeletons (Ries et al. 2009), certain species are highly sensitive to the same aragonite saturation conditions and suffer the effect of ocean acidification with greater intensity (Wittmann and Pörtner 2013). However, those species that are able to calcify and growth under acidic conditions may suffer physiological constrains that impairs fertilization, reproduction, settlement, and their capacity to resist diseases and other stressors (Pörtner 2008, Hofmann et al. 2010, Wittmann and Pörtner 2013, Bednaršek et al. 2016).

c. Shellfish in the Oregon region are vulnerable to ocean acidification

Non-atmospheric sources combined with anthropogenic CO_2 deposition can result in negative ecosystem consequences when they coincide with physical processes such as upwelling that bring O_2-deprived, CO_2-enriched and low-pH waters to nearshore regions (Feely et al. 2009). Acidification can also be exacerbated by non-uniform changes in water circulation and biological processes such as respiration (Feely et al. 2010)

Among the marine species most vulnerable to ocean acidification in marine waters of Oregon are shelled mollusks. Studies have shown that most shelled mollusks are especially sensitive to small pH changes, in particular carbonate saturation states (Barton et al. 2012, Gazeau et al. 2013, Hettinger et al. 2013a) (Fig. 2). Shelled mollusks such as oysters are keystone species in estuarine areas that provide great economic value for local and regional economies, and ecosystems services such as water filtration, estuarine protection, and habitat (Newell 2004). With ocean acidification oysters are at risk due to corrosive waters.

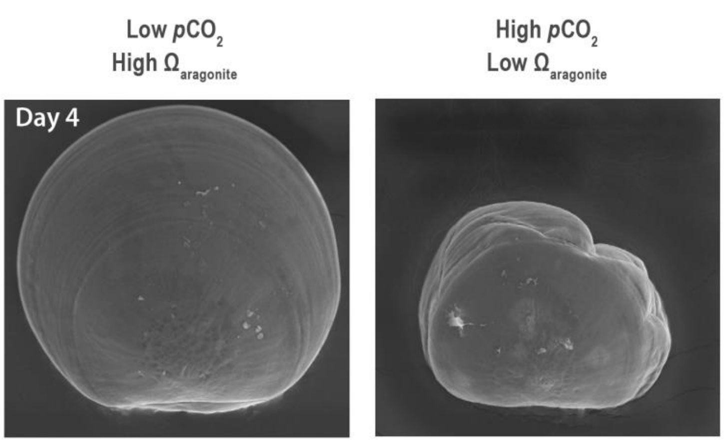


Figure 2 Pacific oyster larvae from the same spawn, raised by the Taylor Shellfish Hatchery in natural waters of Dabob Bay, WA, exhibiting favorable (left, pCO_2 = 403 ppm, $\Omega_{aragonite}$= 1.64, pH = 8.00) and unfavorable (right, pCO_2 = 1418 pp, $\Omega_{aragonite}$= 0.47, pH= 7.49) carbonate chemistry during the spawning period. Scanning Electron Microscopy images show representative larval shells from each condition at four days post–fertilization. *Figure and legend after Barton et al. 2015*

Ocean acidification has already affected oyster populations in estuarine waters of the U.S. Pacific Northwest (Barton et al. 2012, Timmins-Schiffman et al. 2012, Barton et al. 2015). For example, oyster production in the Pacific Northwest declined 22% between 2005 and 2009 because ocean acidification directly affected oyster seed production (Barton et al. 2012, 2015). In fact, Washington and Oregon alone experienced production declines of oyster seed hatcheries of up to 80% from 2006 to 2009 (Chan et al. 2016). In 2006, oyster larval production at the Whiskey Creek Hatchery (Netarts Bay, Oregon) substantially declined due to acidic water conditions leading to halted growth and oyster die offs (Barton et al. 2012).

Oysters and other marine bivalves show permanent negative effects due to ocean acidification when pH and aragonite saturation state decline below certain thresholds (Parker et al. 2009, Lannig et al. 2010, Parker et al. 2012, Barton et al. 2012, Hettinger et al. 2012, Gazeau et al. 2013, Waldbusser et al. 2015a, Barton et al. 2015, Waldbusser et al. 2015b). Barton el al. (2012) first demonstrated that larval production and mid-stage growth of Pacific oyster (*Crassostrea gigas*) significantly declined as rearing water decreased below 7.8 pH units and below 1.7 in aragonite saturation state at an oyster hatchery on the northern Oregon coast (Whiskey Creek Shellfish Hatchery in Netarts Bay) (Fig. 3). In waters with elevated CO_2 concentrations, oyster larvae have difficulty with growth and development, drastically reducing oyster production (Barton et al. 2012). Even when larvae are able to develop under moderate aragonite saturation states, studies show they growth smaller (Waldbusser et al. 2015a) and very few develop to metamorphosis (Barton et al. 2012). Similarly, experimental studies with the Olympia oyster (*Ostrea lurida*), a foundation species of the Pacific Northwest, have shown that as pH declines to 7.8 units (well within the numerical standard pH criteria for the state of Oregon), juvenile oysters exhibited a 41% decreased in shell growth rate, and negative effects persist even after oysters are returned to normal conditions (Hettinger et al. 2012, 2013b).

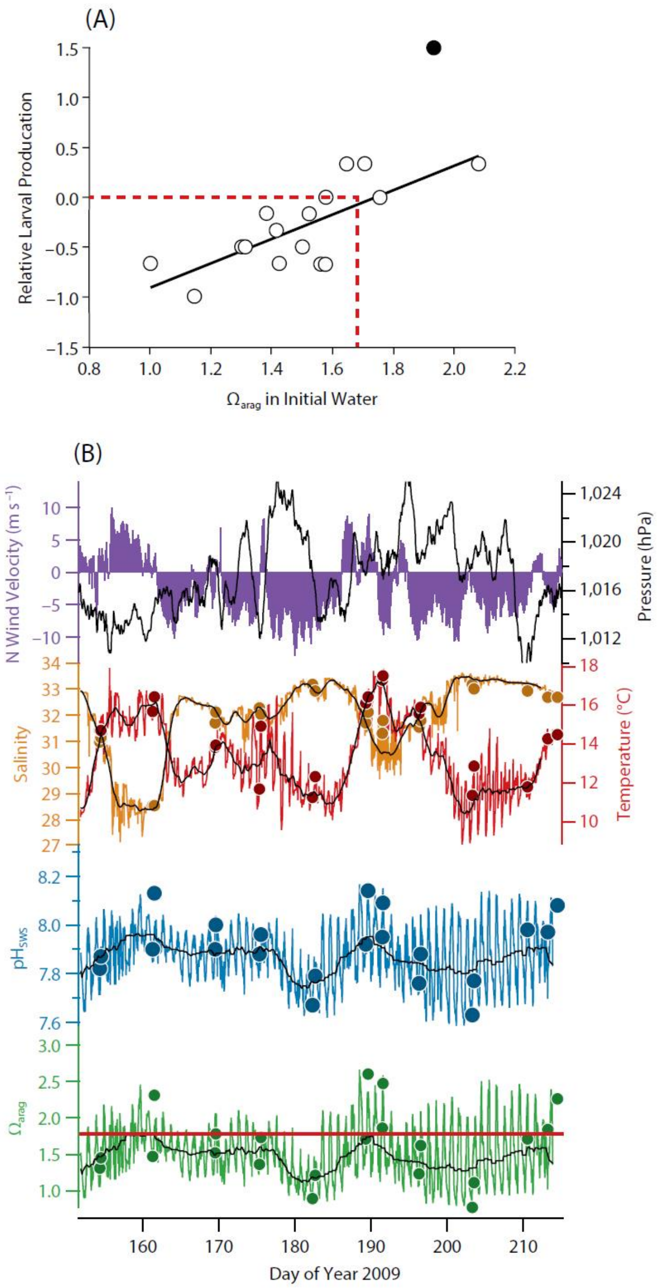


Figure 3 (A) Relative production of Pacific Oyster larvae at the Netarts Bay Whiskey Creek Shellfish Hatchery, Oregon as a function of aragonite saturation state (Ωarag). (B) Wind speed, atmospheric pressure, salinity, temperature, pH, and aragonite saturation state in Netarts Bay during summer 2009. The solid red line shows the threshold aragonite saturation state for no viable

commercial production. *After Barton et al. (2012, 2015)*

Ocean acidification can cost the shellfish industry millions of dollars in economic losses and thousands of jobs. In fact, ocean acidification has already cost the oyster industry in the U.S. Pacific Northwest approximately $110 million dollars and compromised ~3,200 jobs (Washington State Blue Ribbon Panel on Ocean Acidification 2012, Barton et al. 2015). As the shellfish industry faces the increasing effects of ocean acidification, sales and job security will be drastically impacted affecting coastal communities, particularly in areas where fishing and coastal tourism provide the main economic support (Ekstrom et al. 2015, Chan et al. 2016). For example, a Canadian shellfish company reported losses of ~ $10 million during its scallop fisheries in 2014 because acidic waters (WCOAHP 2015a).

These findings in the Pacific Northwest are a wake-up call for action to the state of Oregon. Such negative effects of ocean acidification on shelled mollusk like oyster support the results from laboratory experiments. It is alarming that negative effects of ocean acidification are already seen under current and fluctuating pH conditions. As the ocean acidification trend continues, the shellfish industry along the Oregon coast that include oysters, mussels, scallops and crabs would be subject to substantial economic loses (Chan et al. 2016).

d. Ocean acidification affects crucial zooplankton groups such as pteropods

Ocean acidification in Oregon marine waters also affects important shelled organisms such as pelagic pteropods. Pteropods are small sea snails that use the aragonite form of calcium carbonate to secrete their spiral shells. Pteropods can be used as indicator for water impairment due to their striking vulnerability to ocean acidification. These mollusks are among the calcifier groups most sensitive to declines of aragonite saturation conditions because their delicate aragonite shells (Comeau et al. 2012, Lischka and Riebesell 2012, Bednaršek et al. 2016). In fact, in-life dissolution of pteropods-shells fossil can be used as an indicator of past ocean carbonate saturation conditions (Wall-Palmer et al. 2013). In the California Current Ecosystem, which encompass marine waters of Oregon, pteropods are already impacted by ocean acidification with reduction in abundance and signs of shell damage due to relatively lower pH (Bednaršek et al. 2014, Bednaršek and Ohman 2015). For example, sampling studies along the Washington-Oregon-California coast showed that on average, severe dissolution is found in 53 % of onshore pteropods and 24 % of offshore individuals due to undersaturated waters in the top 100 m with respect to aragonite (Bednaršek et al. 2014).

Field studies have demonstrated that pteropod's shell exhibit increasing dissolution as aragonite saturation declines below 1.3 (Bednaršek and Ohman 2015) and extensive dissolution (e.g., 30%-50% shell surface area) in areas where aragonite saturation state (Ω) is below 1.0 (Bednaršek et al. 2012, Bednaršek and Ohman 2015). Values of Ω aragonite from 1.1 to 1.3 causes stress in pteropods and calcification is maintained at the expense of higher energy consumption (N. Bednaršek Per. Com.). At values below Ω aragonite = 1.1 extensive shell dissolution and irreparable damage is often observed (N. Bednaršek Per. Com.) (Fig. 4). This highlights how aragonite saturation state is an important proxy to directly detect the impacts of ocean acidification on these organisms and how water quality standards must include this parameter (Weisberg et al. 2016).

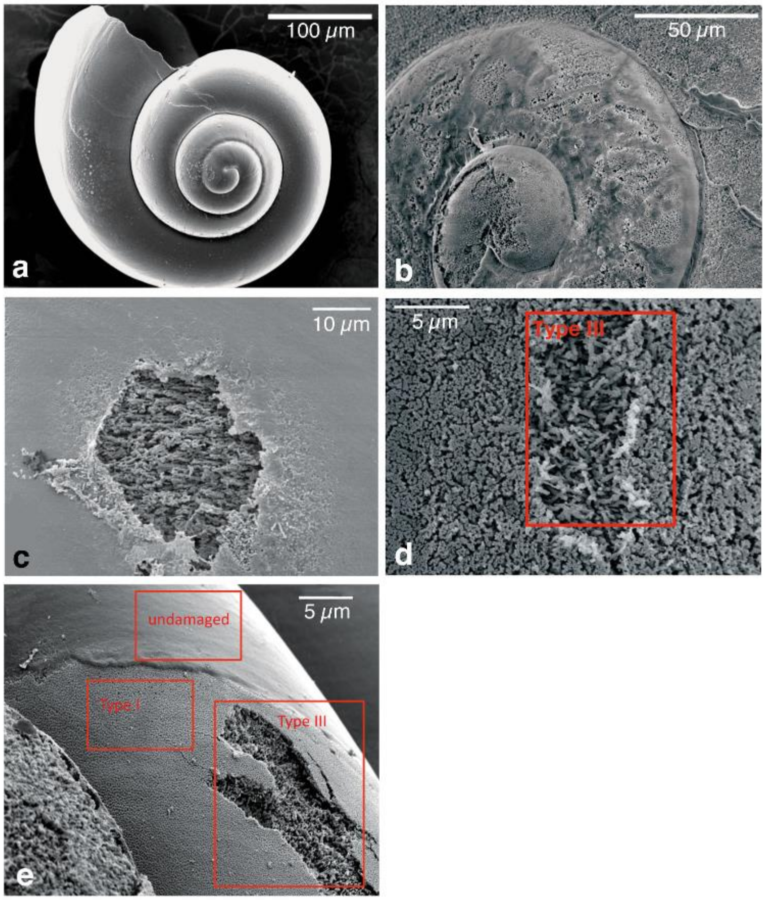


Figure 4 Scanning electronic micrographs illustrating types of shells dissolution in the thecosome pteropod *Limacina helicina*. (a) whole animal with no shell dissolution, (b) Type II dissolution; (c,d) Type III dissolution; (e) mixture of no dissolution, Type I and Type III on a single shell surface. As Ωarag decreases with ocean acidification, pteropods' biological condition deteriorates. Under low level of stress ($\Omega > 1.3$) dissolution is insignificant and shell calcification is maintained. As Ω decreases, dissolution increases, calcification decreases and pteropod shells go through stress to damage to irreparable and ultimately leads to organism mortality. Below $\Omega < 1.1$ moderate to extensive shell damage and decrease calcification occurs. Under undersaturated conditions (Ω <0.9) extensive severe dissolution and absence of calcification occurs. *Figure and legend modified after Bednaršek and Ohman* (2015).

Pteropods are so sensitive to acidic waters that their vertical distribution track changes in water chemistry in the southern California Current System (Bednaršek and Ohman 2015). As aragonite saturation horizon (Ω aragonite = 1.0) shoals (from >100 m to <75 m deep) pteropod abundance declines at depth below 100 m where waters are less saturated with respect to aragonite. In addition, severe shell dissolution is observed at depths where Ω aragonite equals 1.1 to 1.4 (Bednaršek and Ohman 2015). This dynamic in pteropod abundance due to change in sea water chemistry can directly affect those species that feed on them (Doubleday and Hopcroft 2015).

Pteropods are one of the most important species in oceanic marine food webs and their decline could threaten the functioning of entire coastal ecosystems and commercially important fisheries such as salmon (Doubleday and Hopcroft 2015). Pteropods are common prey for important commercial fishes such as anchovies, herring, jack mackerel, sablefish, and pink, chum, Coho, and sockeye salmon (Brodeur et al. 1987, Armstrong et al. 2005, Aydin et al. 2005, Brodeur et al. 2007). In addition, zooplankton, squid, whales and even birds can eat pteropods. Pteropods are the main food sources for commercially and culturally important species such as Pacific salmon, herring, and squid (Doubleday and Hopcroft 2015). Therefore, temporal or spatial reduction in pteropod abundance will have drastic cascading effects on the species that rely on them as the main food source. For example, 30 % of the variability of pink salmon survival during spring-summer in Prince Williams Sound, southern Alaska, has been directly associated with changes in the abundance and distribution of the pteropod *Limacina helicina* (Doubleday and Hopcroft 2015).

Vertical distribution of pteropods is already affected by ocean acidification which may have important consequences for the species that feed on them. Pteropods show vertical migrations to deeper waters during the day and feed in shallower waters at night to avoid predation. Ocean acidification can drastically constrain these vertical migrations by narrowing the range of optimal carbonate saturation and thus calcification. For example, in the Pacific Northwest, diel migration for *L. helicina* is relatively shallow (100 m) because undersaturated waters with respect to aragonite (Mackas and Galbraith 2012). Thus, as pteropods are affected by ocean acidification through calcification and survivorship, ocean acidification indirectly affects species higher in the food web that depend on them as food source.

e. Ocean acidification affects a variety of other marine organisms

Laboratory and mesocosm experiments show that pH and calcium carbonate saturation state levels observed in marine waters of Oregon affect calcification rates of marine calcifiers such coccolithophorids, foraminifera, other mollusks, and sea urchins (Orr et al. 2005, Ries et al. 2009, Doney et al. 2009, Wittmann and Pörtner 2013, Haigh et al. 2015, Yang et al. 2016). Many calcifying species are directly affected by ocean acidification by decreasing calcification rates and compromising growth and survival. Overall calcifying organisms such echinoderms and mollusks tend to show higher sensitivity than crustaceans and fish species (Ries et al. 2009, Wittmann and Pörtner 2013) (Fig. 5). For example, in experimental conditions, calcification rates in temperate corals, urchins, limpets, clams, scallops, and oysters decrease considerably as aragonite saturation state declines below 1.5 corresponding to elevated pCO_2 (i.e., over 900 µatm) (Ries et al. 2009). Studies also suggest that some species of juvenile fish of economic importance in coastal regions are highly sensitive to higher than normal pCO_2 concentrations and lower pH, exhibiting high mortality rates (Ishimatsu et al. 2004).

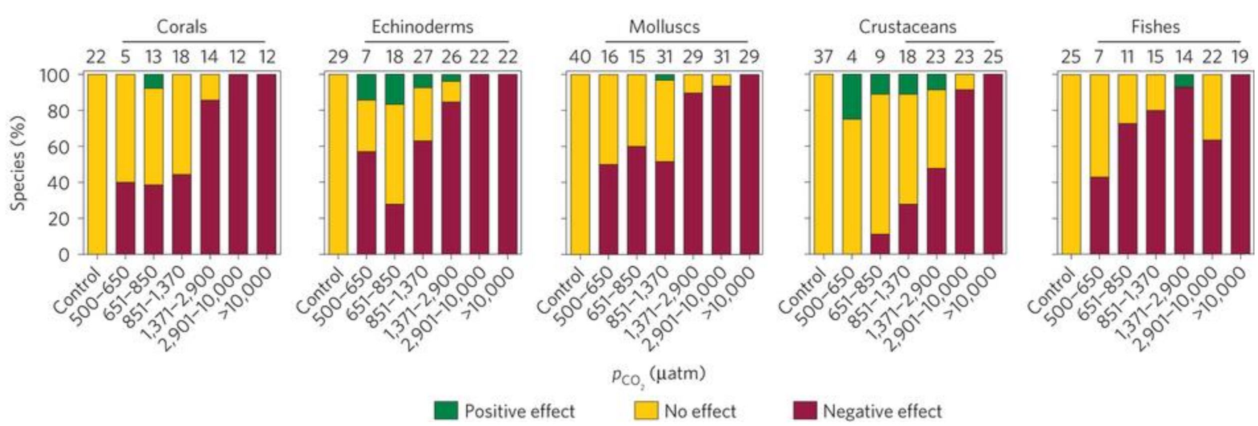


Figure 5 Fractions (%) of coral, echinoderm, mollusk, crustacean and fish species exhibiting negative, no or positive effects on performance indicators reflected as individual fitness in response to the respective p_{CO2} ranges (µatm). The numbers of species analyzed on each CO_2 range are on top of columns. Bars above columns denote count ratios significantly associated with p_{CO2} (according to Fisher's exact test, $p<0.05$, used to analyze species counts of pooled groups of negatively affected species versus not negatively affected species. *Figure and legend modified after Wittmann and Pörtner 2013.*

Ocean acidification will have negative impacts on calcification, survival, growth, reproduction and other physiological processes at the species level in the absence of evolutionary adaptation or acclimatization over the coming decades (Kroeker et al. 2013). These effects can accumulate through marine communities disrupting ecological process and energy fluxes (Nagelkerken and Connell 2015, Linares et al. 2015). Together, these studies forecast drastic changes in species composition with negative impacts through marine populations and communities that ultimately affect ecosystem functionality and services.

f. Local stressors in coastal and estuarine waters magnify anthropogenic ocean acidification

Local stressors can magnify and contribute to acidification in Oregon's coastal and estuarine waters. Local stressors such as eutrophication (Waldbusser et al. 2011, Cai et al. 2011), pollution (Biscéré et al. 2015, Flynn et al. 2015), sulfur dioxide deposition (Doney et al. 2007), hypoxia (Kemp et al. 2005, Melzner et al. 2012), river discharge (Salisbury et al. 2008), runoff from acidic fertilizers (Dentener et al. 2006), and harmful algal blooms (Wu et al. 2014b) can substantially contribute to ocean acidification in coastal waters (Duarte et al. 2013, Waldbusser and Salisbury 2014). Precipitation runoff can also increase acidification in coastal and estuarine waters (Cooley and Doney 2009, Doney et al. 2009, Cheung et al. 2009).

Ocean acidification can magnify the negative effects of toxic algal blooms. Harmful algal blooms can cause mass mortality of wildlife, shellfish harvesting closures, and tremendous risk to human health. Some species of *Pseudo-nitzschia*, a global distributed diatom genus commonly found in marine waters of Oregon, produce domoic acid, a neurotoxin that causes amnesic shellfish poisoning. Studies have shown that acidified conditions due to increasing pCO_2 can increase toxin concentrations as much as five-fold in this harmful microalgae (Sun et al. 2011, Tatters et al. 2012). Toxicity levels have been positively correlated with mortality of shellfish, fish, marine mammals, and can cause deleterious effects in the central nervous system in humans known as paralytic shellfish poisoning (Tatters et al. 2012, Fu et al. 2012, Tatters et al. 2013). For example, results from laboratory experiments indicate that levels of the toxin domoic acid and growth rate in the diatom *Pseudo-nitzschia multiseries* increases as pCO_2 in water increases from 220 to 730 ppm (Sun et al. 2011).

During spring and summer in the Pacific Northwest where relatively warmer waters, coastal upwelling, and increase freshwater runoff occur, coastal toxic algal blooms along the coast of California, Oregon, and Washington may becoming more common and intense. The Pacific Northwest (including Oregon) had one of the worst harmful algal blooms recorded in 2015 with the highest concentrations of domoic acid yet observed (NOAA Fisheries 2015). It is likely that ocean acidification and coastal runoff may have increased their toxicity. For example, the toxicity of some harmful algal blooms can increase with ocean acidification (Sun et al. 2011) and with land-runoff and/or water column stratification (Hallegraeff 2010).These toxic algal blooms led managers to close down the entire west coast recreational and commercial crab fisheries from the southern Washington coast to Southern California (Ayres 2015). The toxicity of harmful algal blooms increases with ocean acidification and eutrophication can alter phytoplankton growth and succession (Wu et al. 2014b, Flynn et al. 2015).This suggests that coastal waters could be impaired with ocean acidification by failing water quality standards for toxic and other deleterious organic and inorganic substances, which were indirectly and partially driven by low water pH.

g. Ocean acidification can be partially addressed locally

Currently, several approaches can be used to prevent locally intensified ocean acidification. Recently, the West Coast Ocean Acidification and Hypoxia Science Panel working in partnership with the California Ocean Science Trust published a report highlighting major findings, recommendations, and actions that West Coast states can take now to address ocean acidification locally (Chan et al. 2016). This report suggested that the effectiveness of local actions will be higher in semi-enclosed water bodies such as estuaries and bays where local physical-chemical processes dominated over oceanic forcing (Chan et al. 2016). As such local actions will be paramount in Oregon since semi-enclosed water bodies such as estuaries and small bays represent a substantial portion of marine waters in the state. Oregon has already a legal framework to address not only local stressors that amplify the effects of ocean acidification, but also reduce local and state level carbon dioxide emissions that primarily contribute to the problem.

Ocean acidification can have a localized impact and often acts synergistically with other stressors. Marine species have a limited capacity to deal simultaneously with several stressors, and often the negative combined effects of ocean acidification with other local stressors are stronger than the sum of their parts. This is because ocean acidification in coastal areas can be intensified by the negative effects of local stressors (e.g., pollution, hypoxia, warming, and runoff) (WCOAHP 2015b). Additional declines of pH, aragonite saturation state, and dissolved oxygen associated with local stressors can suddenly push marine species across a critical threshold that drastically impairs their physiology and can cascade up through the food web affecting entire ecosystems (Nagelkerken and Connell 2015, Haigh et al. 2015). As marine species fare better dealing with one stressor instead of multiple stressors, the most practical, fast, and direct approach to deal with ocean acidification in the short term is to eliminate other local stressors and therefore increase the resilience of marine species to corrosive waters.

Under the Clean Water Act, Oregon has ample authority to address local sources that contribute to ocean acidification, including storm water runoff, sewage contamination, and management actions to build resilience. Anthropogenic ocean acidification combined with local stressors that lower pH greatly magnifies the acidification problem with drastic effects in local economies (Chan et al. 2016). Ocean acidification can be especially problematic in estuarine and coastal waters adjacent to urban areas drastically reducing water quality that impairs the survival and growth of marine species. By addressing local pollution, eutrophication, river runoff and estuary erosion (among others), the state of Oregon will not only prevent the magnification of the ocean acidification problem, but also provide marine organisms with better capacity and more time to resist ocean acidification while we work globally to reduce atmospheric CO_2.

Although the primary solution to eliminate ocean acidification is to drastically curb CO_2 emissions globally, local management actions that directly address water quality by eliminating pollution, hypoxia, excess of land-based nutrient runoff, and sedimentation from land erosion will substantially ameliorate the deleterious effects of ocean acidification on marine species

(Chan et al. 2016). Addressing local stressors may alone improve the health of coastal waters and protect coastal economies that depend on shellfish fisheries. Moreover, under the Clean Water Act, Oregon has the authority to reduce atmospheric CO_2 that contributes to water quality violations due to ocean acidification. The Clean Water Act has a long history of being used to address water pollution from atmospheric deposition. For example, section 303(d) of the Clean Water Act has been used to address cross-border pollution from atmospheric mercury, PCBs, and acid rain. Oregon can do its part, as well as hold adjacent states accountable for their contributions to ocean acidification.

3. Current water quality criteria for pH are inadequate to address ocean acidification

The estuarine/marine habitat pH criteria for Oregon marine and estuarine waters are inadequate to protect aquatic life. Based on the best available scientific information on the deleterious effect of ocean acidification on marine life, these pH standards are inadequate, because negative biological effects can be observed at pH levels well within the current range that is considered normal. Thus, the state of Oregon in conjunction with the EPA should develop new water quality standards for ocean acidification (either numerical or narrative) that better reflect the natural variability and potential negative effects of acidification on vulnerable coastal and estuarine species

Current water quality criteria for pH were developed over four decades ago and are scientifically inadequate to address the effects of ocean acidification. The numerical criteria are not based in the most current science and are not ecological relevant for marine and estuarine species (Chan et al. 2016). These thresholds, while providing guidance, are insufficient with respect to ocean acidification applications (Chan et al. 2016). Several studies (see above) have shown biological impacts at pH levels well above 7.5 units. Moreover, this pH range represents up to two order of magnitude difference in acidity since the pH is in logarithm scale. Finally, a deviation of no more than 0.2 units from ambient is difficult to apply. The state and regional water boards must take steps to define historical ambient pH levels for its waters.

New ecologically meaningful water quality criteria for ocean acidification must be developed and recent studies recommend more appropriate approaches (Weisberg et al. 2016). In addition, ocean acidification water criteria should be expanded to include other acidification parameters (e.g., pCO_2, aragonite saturation state, carbonate ions concentration) that may be more relevant than pH and may affect many marine species (Chan et al. 2016). For example, aragonite saturation state is more biologically relevant than pH for shell formation in calcifying organisms such as pteropods and oysters, and recent studies have already established chronic and acute thresholds that can be used (see above). In contrast, parameters such as pCO_2 instead of pH are more relevant for fish which can drastically impair their ability to avoid predators, find food, and identify suitable habitat (Ishimatsu et al. 2004, Dixson et al. 2010, Ferrari et al. 2012).

4. Oregon's water bodies impaired by ocean acidification

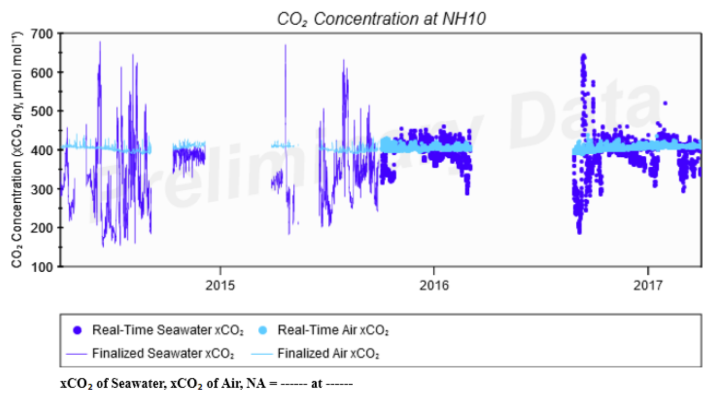
This section is an analysis of a series of water bodies across Oregon that may be already impaired by ocean acidification.

a. **NH-10 off Newport, OR** (44.6°N, 124.3°W).

Station description: The Newport Hydrographic (NH-10) mooring is located in the northern California Current Ecosystem along the central Oregon coast, about 12 miles to the west of Newport and anchor on the inner shelf at 85 m. This region supports economically important ground-fish and crab fisheries due to diverse and productive benthic and near shore ecosystems. The area around the mooring experiences a highly-variable biogeochemistry because river freshwater input and strong seasonal upwelling[1]. The combination of upwelling and high productivity can lead to bottom water hypoxia.[2]

Impairment: Although the recoded pH values since April 2014 fall within the normal pH criteria (7.0-8.5) for marine waters of Oregon (Fig. 6), these waters may be impaired by ocean acidification based on the narrative criteria. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the complete set of ocean acidification parameters for this mooring from April to September 2014 can be found at: http://cdiac.ornl.gov/ftp/oceans/Moorings/NH10_124W_44N/NH10_124W_44N_Apr2014_Sep2014.csv



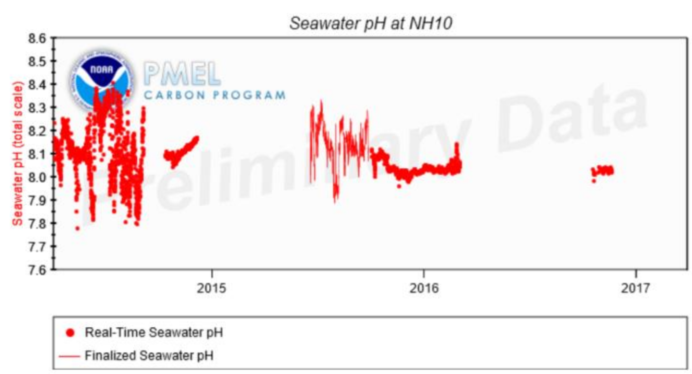


Figure 6 Real time data for pCO_2 and pH at NH10 from April 2014 to present. Note that significant gaps are present in the records. Current graphs can be found at: https://www.pmel.noaa.gov/co2/story/NH-10

[1] PMEL 2017, NH-10 Description https://www.pmel.noaa.gov/co2/story/NH-10
[2] PMEL 2017, NH-10 Description https://www.pmel.noaa.gov/co2/story/NH-10

b. **Coastal Endurance Oregon Inshore Surface Mooring** - Seafloor Multi-Function Node (44.65828 ºN, -124.09525 ºW).

Station description: The Oregon Inshore Surface Mooring (CE01ISSM) site with the Seafloor Multi-Function Node is part of the Coastal Endurance Array anchored at ~25 m deep and located at about 1.73 miles west Agate Beach, Newport, Oregon. The mooring uses a CE01ISSM-MFD35-06-PHSEND000 to measure pH at 25 m deep. This area is highly productive with a dynamic upwelling environment.[3]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from April 15, 2014 to October 29, 2016 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-MFD35-06-PHSEND000

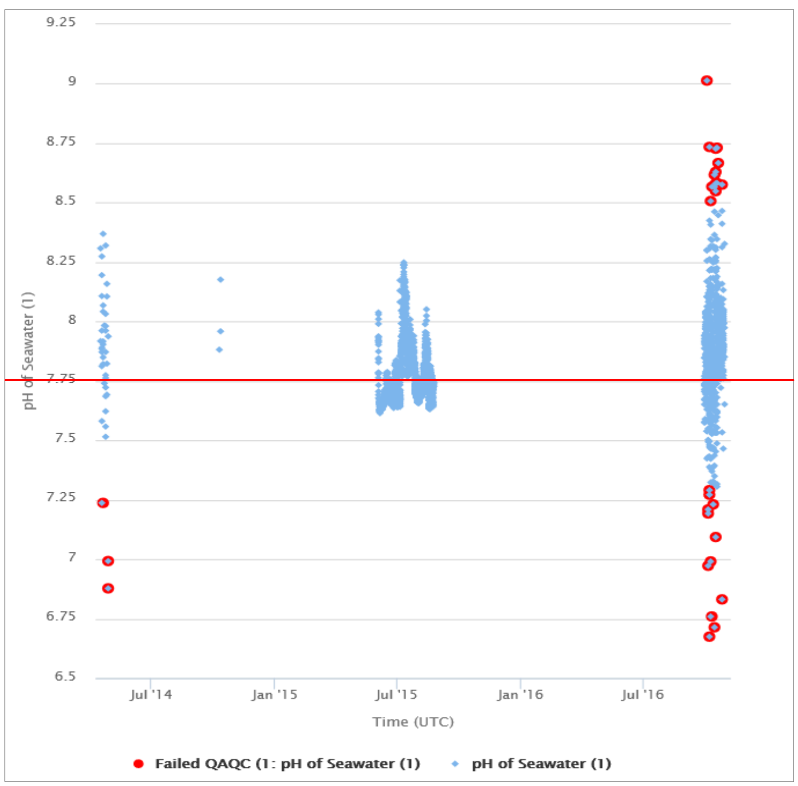


Figure 7 Real time data for pH at the Coastal Endurance Oregon Inshore Surface Mooring Seafloor Multi-Function Node (44.65828 ºN, -124.09525 ºW) from April 15, 2014 to October 29, 2016 using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graphs can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-MFD35-06-PHSEND000.

[3] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

c. **Coastal Endurance Oregon Inshore Surface Mooring** – Near Surface Instrument Frame (44.65975 ºN, -124.09504 ºW).

Station description: The Oregon Inshore Surface Mooring (CE01ISSM) site with the Seafloor Multi-Function Node is part of the Coastal Endurance Array anchored at ~7 m deep and located at about 1.73 miles west of Agate Beach, Newport, Oregon. The mooring uses a CE01ISSM-MFD35-06-PHSEND000 to measure pH at 7 m deep. This area is highly productive with a dynamic upwelling environment.[4]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from September 15, 2014 to October 29, 2016 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-RID16-06-PHSEND000

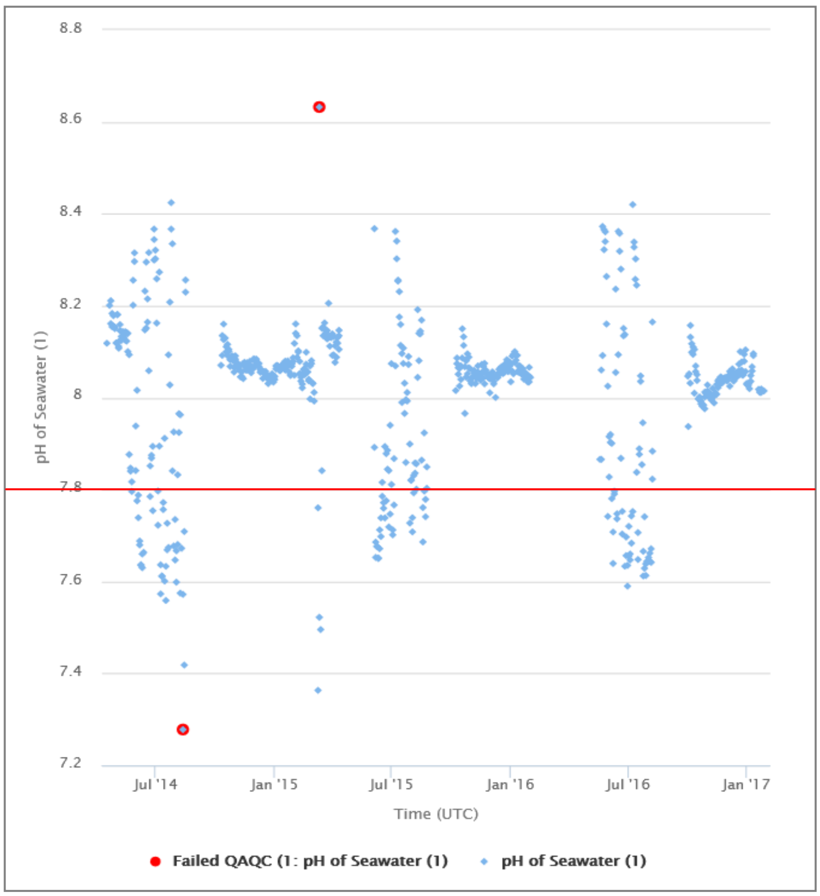


Figure 8 Real time data for pH at the Coastal Endurance Oregon Inshore – Near Surface Instrument Frame (44.65975 ºN, -124.09504 ºW) from April 15, 2014 to October 29, 2016 using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE01ISSM-RID16-06-PHSEND000

[4] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

d. **Coastal Endurance Oregon Shelf Cabled Benthic Experiment Package -** Low-Power JBox (LJ01D) (44.63708 ºN, -124.30595 ºW).

Station description: The Oregon Shelf Cabled Benthic Experiment Package **(CE02SHBP)** site with the Low-Power JBox (LJ01D) node is part of the Coastal Endurance Array anchored at ~80 m deep and located at about 12 miles west of Newport, Oregon. The mooring uses a CE02SHBP-LJ01D-10-PHSEND103 to measure pH at 80 m deep. This area is highly productive with a dynamic upwelling environment.[5]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from September 25, 2014 to April 3, 2017 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHBP-LJ01D-10-PHSEND103#CE02SHBP-LJ01D-10-PHSEND103/streamed_phsen-data-record

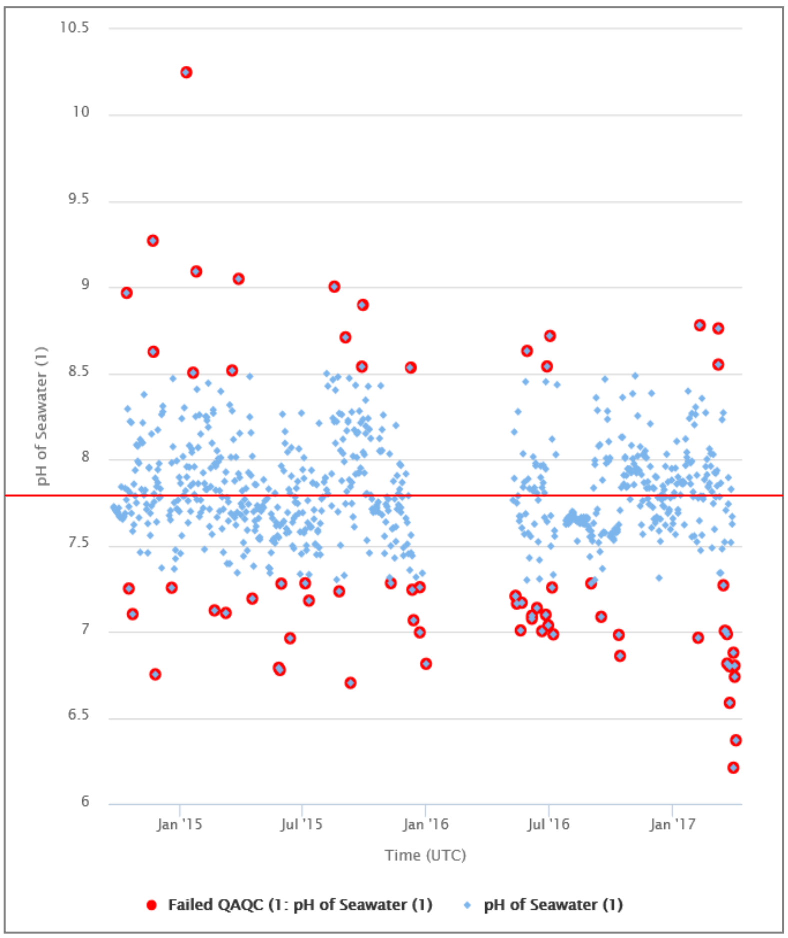


Figure 9 Real time data for pH at the Coastal Endurance Oregon Shelf Cabled Benthic Experiment Package - Low-Power JBox (LJ01D) (44.63708 ºN, -124.30595 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHBP-LJ01D-10-PHSEND103#CE02SHBP-LJ01D-10-PHSEND103/streamed_phsen-data-record

[5] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

e. **Coastal Endurance Oregon Shelf Surface Mooring -** Near Surface Instrument Frame (44.63565 ºN, -124.30427 ºW).

Station description: The Coastal Endurance Oregon Shelf Surface Mooring (CE02SHSM) site with the Near Surface Instrument Frame node is part of the Coastal Endurance Array anchored at ~7 m deep and located at about 12 miles west of Newport, Oregon. The mooring uses a CE02SHSM-RID26-06-PHSEND000 instrument to measure pH at 7 m deep. This area is highly productive with a dynamic upwelling environment.[6]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from April 2, 2015 to October 6, 2016 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHSM-RID26-06-PHSEND000#CE02SHSM-RID26-06-PHSEND000/telemetered_phsen-abcdef-dcl-instrument

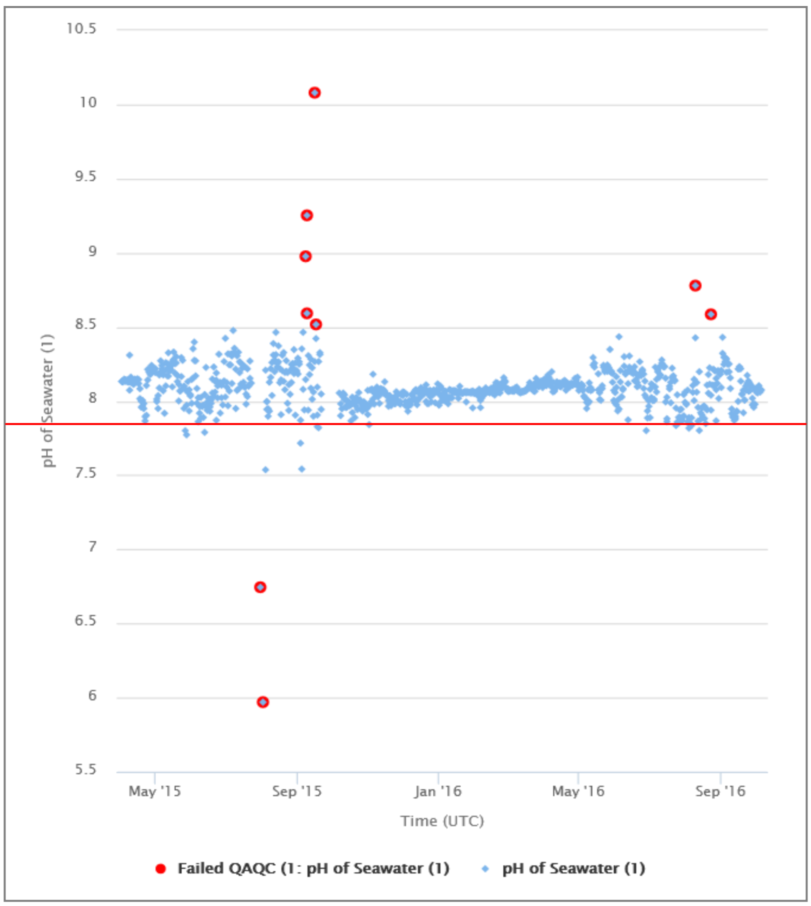


Figure 10 Real time data for pH Coastal Endurance Oregon Shelf Surface Mooring - Near Surface Instrument Frame (44.63565 ºN, -124.30427 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE02SHBP-LJ01D-10-PHSEND103#CE02SHBP-LJ01D-10-PHSEND103/streamed_phsen-data-record

[6] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

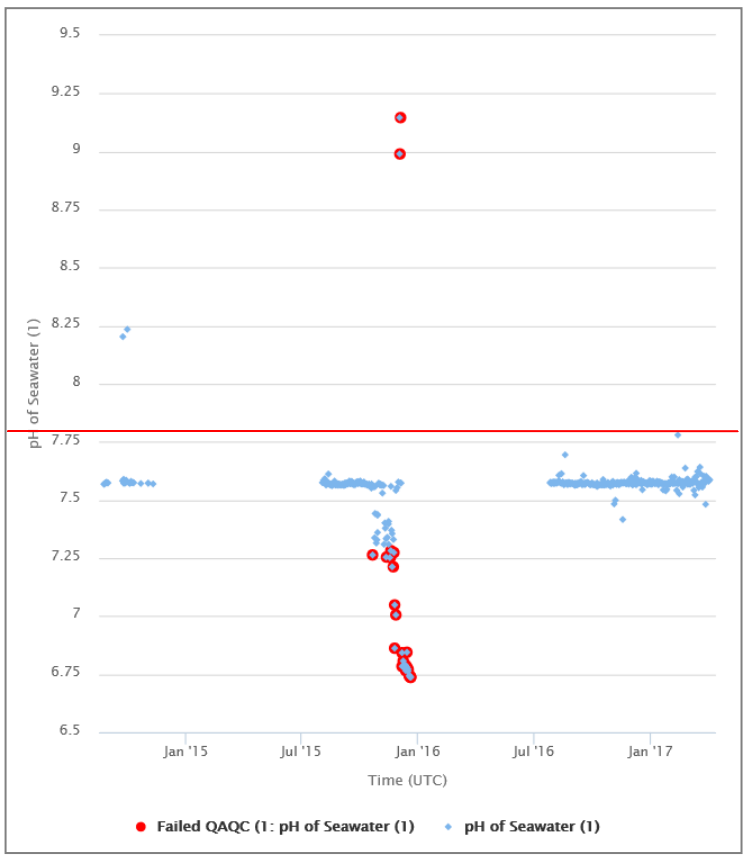
f. **Coastal Endurance Oregon** Offshore Cabled Benthic Experiment Package - Low-Power JBox (LJ01C) (44.3695 ºN, -124.95369 ºW)

Station description: The Coastal Endurance Oregon Offshore Cabled Benthic Experiment Package (CE04OSBP) site with the Low-Power JBox (LJ01C) node is part of the Coastal Endurance Array anchored at ~580 m deep and located at about 12 miles west of Newport, Oregon. The mooring uses a CE04OSBP-LJ01C-10-PHSEND107 instrument to measure pH at 580 m deep. This area is highly productive with a dynamic upwelling environment.[7]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from August 25, 2014 to April 3, 2017 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSBP-LJ01C-10-PHSEND107#CE04OSBP-LJ01C-10-PHSEND107/streamed_phsen-data-record

Figure 11 Real time data for pH Coastal Endurance Oregon Offshore Cabled Benthic Experiment Package - Low-Power JBox (LJ01C) (44.3695 ºN, -124.95369 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSBP-LJ01C-10-PHSEND107#CE04OSBP-LJ01C-10-PHSEND107/streamed_phsen-data-record



[7] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

g. **Coastal Endurance Oregon Offshore Surface Mooring -** Near Surface Instrument Frame (44.36485 ºN, 124.94343 ºW)

Station description: The Coastal Endurance Oregon Offshore Surface Mooring (CE04OSSM) site with the Near Surface Instrument Frame node is part of the Coastal Endurance Array anchored at ~7 m deep and located at about 42 miles west of Yachats, Oregon. The mooring uses a CE04OSSM-RID26-06-PHSEND000 instrument to measure pH at 7 m deep. This area is highly productive with a dynamic upwelling environment.[8]

Impairment: This water body should be classified as impaired because based on the narrative criteria water quality is not at the highest possible level and may have deleterious effects on marine organisms. Several pH measurements fall below 7.8 which has been shown to have deleterious effects on Pacific oyster (Barton et al. 2012), Olympia oyster (Hettinger et al. 2012, 2013a), and pteropods (Weisberg et al. 2016).

Data availability: Readily available data and metadata for the completed set of ocean acidification parameters for this mooring from April 7, 2015 to March 19, 2017 is found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSSM-RID26-06-PHSEND000#CE04OSSM-RID26-06-PHSEND000/telemetered_phsen-abcdef-dcl-instrument

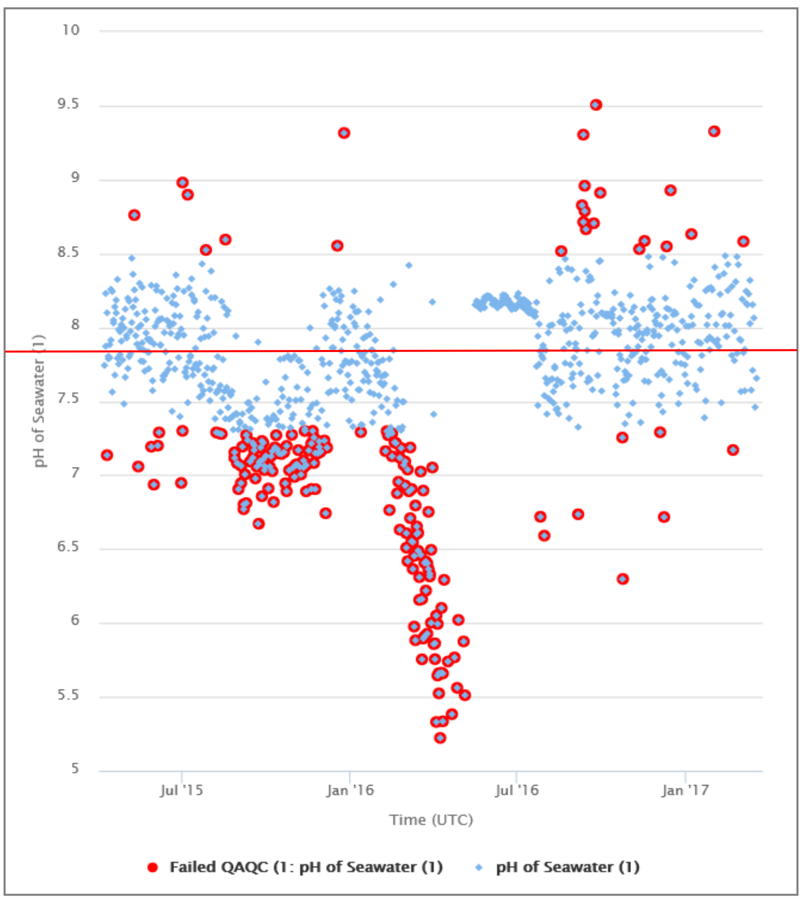


Figure 12 Real time data for pH Coastal Endurance Oregon Offshore Surface Mooring - Near Surface Instrument Frame (44.36485 ºN, 124.94343 ºW) using the telemetered pH sensor instrument. Note that significant gaps are present in the records. Red circles indicate pH measurements that failed quality accuracy and control. Red horizontal line is pH of 7.8. Current graph can be found at: https://ooinet.oceanobservatories.org/data_access/?search=CE04OSSM-RID26-06-PHSEND000#CE04OSSM-RID26-06-PHSEND000/telemetered_phsen-abcdef-dcl-instrument

[8] Oregon Inshore Surface Mooring http://oceanobservatories.org/site/ce01issm/

5. Oregon must evaluate data related to ocean acidification parameters from several readily available sources

Oregon has a duty to evaluate ocean acidification parameters during its water quality assessment (EPA 2010). Oregon must "*evaluate all exiting and readily available water quality-related data and information to develop the list*" 40 C.F.R. § 130.7(b)(5). Beyond reviewing the information submitted by the Center, Oregon must also evaluate pH and other monitoring data that is readily available and seek out additional ocean acidification data from state, federal, and academic research institutions. EPA's 2010 memo and Integrated Report Guidance discussed several sources, including the NOAA data (EPA 2010: 7-9; EPA Guidance 30-31). There are several sources for high resolution ocean acidification data that will be available in the near future.

The state must obtain and consider data being collected from Oregon State, the University of Washington, National Oceanic and Atmospheric Administration, the ocean Observatories Initiative, and other research institutions. These institutions are conducting research surveys as well as have permanently moored instruments that are gathering information about ocean acidification. For example, much of these data, including measurements of CO_2, dissolved oxygen, turbidity, temperature, and salinity dating back to 2005, have been archived and are available to Oregon. Data relevant to ocean acidification in Oregon has also been transmitted to and made available by the Pacific Marine Environmental Laboratory. Finally, the Center urges the state to improve its own monitoring program so that it can detect ocean acidification related water quality problems at a higher temporal resolution.

The following are additional sources from which Oregon can obtain and evaluate data from:

- NOAA Pacific Marine Environmental Laboratory Carbon Program
- Oregon State University, College of Earth, Ocean and Atmospheric Sciences
- Ocean Observatories Initiative
- NOAA National Ocean Data Center
- National Data Buoy Center
- University of Washington's Oceanic Remote Chemical Analyzer (ORCA) Group
- Northwest Association of Networked Ocean Observing Systems (NANOOS)
- Integrated Ocean Observing System
- Global Ocean Acidification Observing Network

Oregon should obtain and evaluate data on all relevant parameters of ocean acidification that are available from these and other sources including it its own water quality database. Coastal and estuarine ocean acidification parameters were not considered for the most part in the last Integral Report. Thus Oregon should seek, analyze, and discuss data on water quality parameters relevant to ocean acidification.

6. Conclusion

The Center urges the state of Oregon and the EPA to include ocean acidification as water quality issue and to include water quality objectives for pH that avoid harmful biological impacts in the upcoming integrated report. Even though most pH values of marine waters in Oregon may fall within the ranges attaining pH numeric standards for the state, some water bodies are too acidic which harm calcifying organisms such as oysters. Scientific evidence over the past decade clearly shows that marine waters of Oregon are becoming more acidic, negatively affecting the growth and survival of important calcifying coastal and estuarine species. It is imperative that Oregon and the EPA take concern and action now on ocean acidification to address this increasingly important water quality problem before it has devastating consequences on coastal and estuarine ecosystems. Delaying action could make future management strategies substantially less effective and likely more costly. Minimizing or preventing additional local stressors on coastal ecosystems such as nutrient inputs associated with coastal development and urbanization can ameliorate the compounding threats of ocean acidification. In estuarine waters, natural factors such as freshwater inputs, restricted circulation, and hypoxic conditions can amplify the effects of anthropogenic carbon dioxide deposition and nutrients inputs and predispose these ecologically and economically important habitat to corrosive waters. The actions that Oregon can take now based on the best available science would ameliorate the negative effects of ocean acidification. Inaction on ocean acidification will result in drastic biological, ecological and socioeconomic negative effects that will be more severe in coastal and estuarine environments compromising sensitive species, ecosystem services and the human populations that rely on them.

Please contact me if you require further information or have questions.

Sincerely,

....

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7. **Literature cited***

*All references were sent in a CD with a hard copy of this letter and associated data.

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